

For Imaginary Dimensions and Causal Brane-Worlds

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We address the nature of spacetime by looking squarely at the wave function. First we consider mounting evidence in support of the following assertions:

- a. The wave function is ontic (an objectively present, holistic entity).
- b. The wave function is non-local (holistic over space).
- c. The wave function is time-symmetric (holistic over time).

Rather than endlessly debate these statements we ask the rhetorical question: What if these three assertions are true? What are the logical consequences?

We begin with time-symmetry, sometimes erroneously called time-reversal. On the basis of retro-causal effects demonstrated by delayed-choice experiments along with subsequent time-symmetric approaches to QM we deduce that the wave function is extended over time as well as over space. It follows that the wave function is a 4-dimensional object and hence cannot live in our 3-space. Being 4-dimensional it requires a 4-space, which necessarily must coincide with our 3-space, since the 4-dimensional wave function always corresponds to its cross-section in the 3-space. Whatever the philosophical implications of such an arrangement, it derives directly from the evidence and therefore is admitted for logical scrutiny.

It follows that our 3+1 spacetime, far from being a block universe, consists of a 3-space passing over the fourth dimension of a 4-space. This fourth spatial dimension is not time itself but the *spatial precursor* to time; it is the *relative spatial motion* that manifests as the phenomenon of time (all dimensions being orthogonal). While our 3-space exists only in the present moment (t_{now}), a wave function extending from an emission event at time t_1 to an absorption event at time t_2 continues to evolve holistically in the 4-space while $t_1 < t_{\text{now}} < t_2$. (Note that this notion of “spatial motion” might be more fundamentally understood as *propagation of energy*, but the term is retained here for logical continuity, since that is the observed effect – time does appear to “flow” after all.)

The wave function (as currently formulated) has complex phase while being extended in real 3-space, for a total of five dimensions to represent the wave function (conventionally considered). So, if the wave function is indeed ontic, we face directly the problem of imaginary dimensions. Our solution is to simply accept the evidence: the fourth dimension of the 4-space is imaginary. When the real part of the wave function’s complex phase is understood as one of our regular spatial dimensions the wave function becomes 4-dimensional, with the fourth dimension being imaginary. It follows that the imaginary axis of the wave function correlates to time in our 3-space; thus does time enter QM as a dynamic variable.

Such a space having three real and one imaginary dimensions is familiar to physicists, being known as *Euclidean spacetime*, where the time dimension of Minkowski spacetime is rotated (Wick rotation) into “imaginary time” according to $\tau = it$ ($c = 1$). Hence the efficacy of imaginary time in quantum theory: so-called Euclidean spacetime is where the four-dimensional wave function finds its home, but with the fourth dimension interpreted here as spatial, according to $\boldsymbol{w} = i\boldsymbol{t}$ (note that imaginary terms are bolded for logical clarity). For present purposes we denote this 4-space *Minkowski 4-space*, where:

$$ds^2 = dx^2 + dy^2 + dz^2 + d\boldsymbol{w}^2 \quad (1)$$

Since all four dimensions are spatial, the displacement s must also be interpreted as spatial. This is crucial to what follows. We introduce the equation for the propagation of the wave function, $v_{\text{ph}} v_{\text{g}} = c^2$ (2), where v_{g} is group velocity, interpreted as the velocity of the associated particle, and v_{ph} is phase velocity, interpreted as the

propagation of the wave function itself, with c being the speed of light.

Since we know that photons adhere to a light cone in Minkowski spacetime, it follows from the propagation formula (2) that the wave function itself will adhere to a null cone in Minkowski 4-space. Technically, therefore, there is no spatial distance, s , between any parts of the photon wave function, no matter how unintuitive this may appear from our perspective in 3+1 spacetime. This accounts for the “quantum connection” being unattenuated (over any distance), discriminating (confined to specific null cones) and faster than light (instantaneous).

While this arrangement accounts for the holistic behaviour of the photon (massless) wave function over both space and time, it does not account for the wave function of a massive particle, which according to the propagation formula will travel at infinite speed for a particle at rest (which is definitely not on a null cone).

Since the wave function evolves in the 4-space, this dynamical process requires a time dimension in the 4-space, yielding a 4+1 spacetime. We call 4-space time t_4 , while time in the 3-space we denote t_3 . Consequently we have two reasons for requiring an additional dimension: as a spatial precursor for time in the 4-space, t_4 ; and to account for energy and mass. Hence we introduce a second imaginary dimension ν , such that:

$$ds^2 = dx^2 + dy^2 + dz^2 + d\boldsymbol{w}^2 + d\nu^2 \quad (3)$$

This implies that a 5-space interpenetrates the 4-space and the 3-space, so in fact the complete wave function is 5-dimensional. We denote this space *Minkowski 5-space*, which includes two dynamic imaginary dimensions in addition to a real 3-space. We presume that the (massive particle) wave function will always adhere to a null geodesic in Minkowski 5-space ($s = 0$).

We consider a wave function extending from the origin of Minkowski 5-space over real distance x ($y = z = 0$). We let $\boldsymbol{w} = \mathbf{i}ct$ and $\nu = \mathbf{i}V$. For a particle at rest, from (2) we find $\boldsymbol{w} = 0$. To satisfy the null metric (3) it follows that $V_0 = x$. We also note that the wave function frequency relative to the ν dimension, hence energy and mass, will be inversely proportional to V , such that $m/m_0 = V_0/V$. On this basis, beginning with (2) and (3), we trivially derive the mass transformation equation according to Special Relativity.

Using similar reasoning, accelerating a particle from its rest frame in 3+1 spacetime equates to some reduction in the V coordinate in that frame, which requires energy, this being the mechanism of inertia.

We argue on both technical and philosophical grounds that the 5-space marks the end of the dynamical process; the \boldsymbol{w} and ν dimensions are in motion relative to a higher imaginary dimension \boldsymbol{u} which is itself static, resulting in *real* time t_5 in the 5-space. Time in the 4-space therefore originates in the motion of the imaginary dimension ν in real time t_5 , so time in the 4-space is *imaginary* ($dt_4 = d\nu/dt_5$). Time in our 3-space thus derives from the motion of the imaginary dimension \boldsymbol{w} in imaginary time t_4 ($dt_3 = d\boldsymbol{w}/dt_4$) – hence physical time is *real*.

Here is unveiled a great mystery, the logical underpinnings of the Wick rotation, moving between 3+1 spacetime and the 4-space. How does motion of the imaginary dimension \boldsymbol{w} become real time t_3 ? In a nutshell, physical time is real because time in the 4-space is imaginary. (It follows that time is equivalent to velocity over a higher dimension, which is precisely correct – hence the *apparent* dimensional inconsistencies).

To briefly review, we erect a spacetime framework supporting quantum non-locality and retro-causality. We derive a mechanism underpinning time and explain the Wick rotation. We derive the mass transformation equation according to Special Relativity *on the basis of both quantum and relativistic principles*. Hence do Special Relativity and the wave function meld in the 5-space, becoming aspects of an overarching framework, with General Relativity looming in the shadows. Furthermore, we propose a mechanism by which Kaluza’s 4+1 Einstein-Maxwell theory becomes directly applicable to the 5-space. Thus we submit that the essential logical elements are in place supporting the formulation of a consistent quantum theory of gravity.